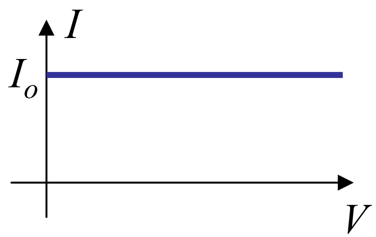
Applications of Diodes and Transistors to Sources

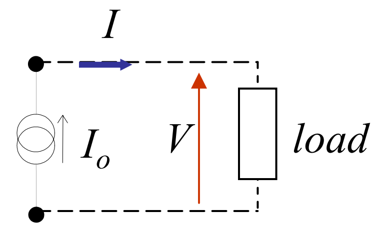
- **Current & Voltage Sources based on transistor**
  - **FET-based**
  - **BJT-based**

- **Signal Shaping**
  - Rectification
  - Clamping

Ideal Sources

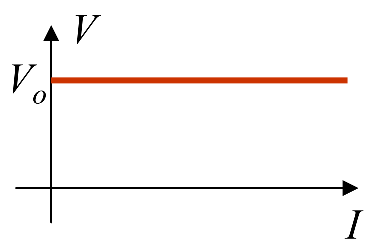
Ideal Current source :

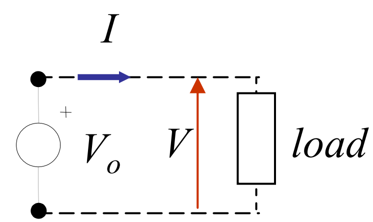




→ **Current** provided by the source is **independent** of load

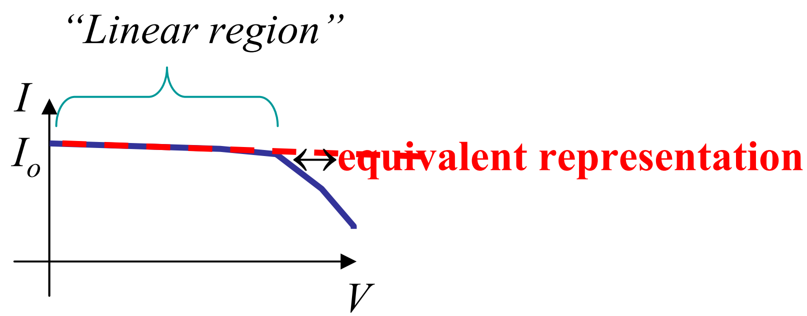
Ideal Voltage source :





→ **Voltage** at source terminals is **independent** of load

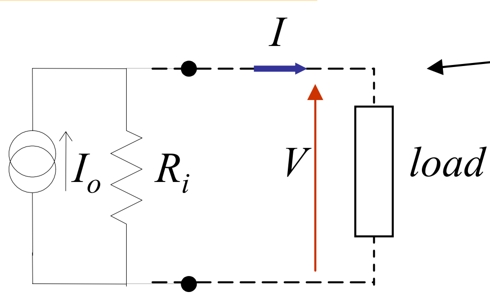
Real Current Source



→ The linear domain is the range where the component effectively operates as a current source

Equivalent schematic:

Assumption is : $V \in$ linear region



$$\rightarrow I = I_o - \frac{V}{R_i}$$

This is the equivalent of Thevenin Circuit for a voltage source it is called Norton equivalent circuit.

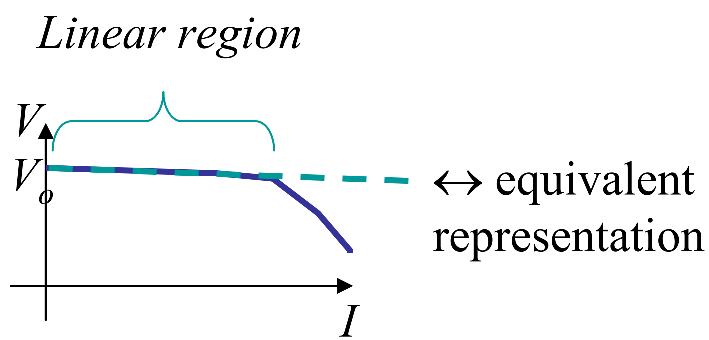
$\Rightarrow I \cong const = I_o$

As long as I >> current in internal resistance $\left(\frac{V}{R_i}\right)$

R_i = "internal resitance"
($G_i = 1/R_i$ = *internal conductance)*

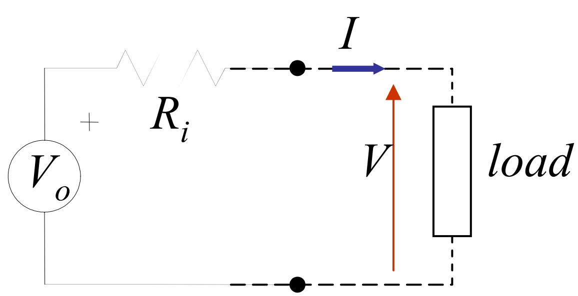
current source ↔ R_i >> *V/I* = Z_e = *load input impedance.*

Real Voltage Source



Equivalent schematics (Thevenin circuit):

assumption : $V \in$ linear region



$$\rightarrow V = V_o - R_i I$$

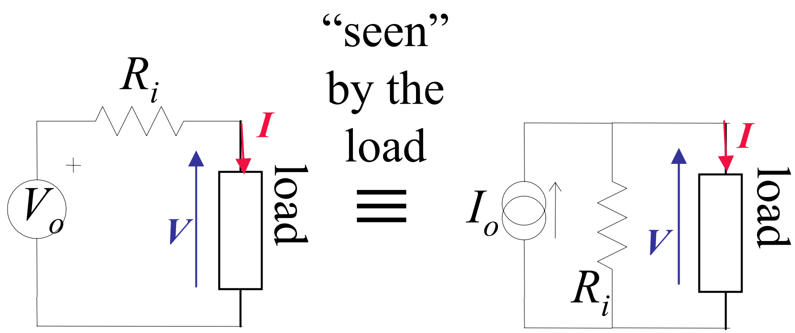
$$\Rightarrow V \cong cst = V_o$$

As long as the voltage drop across R_i is small compared to V $(R_i I << V)$

$$\text{Voltage source} \leftrightarrow R_i << Z_e$$

Current versus Voltage Source -- Equivalence

In fact…



with

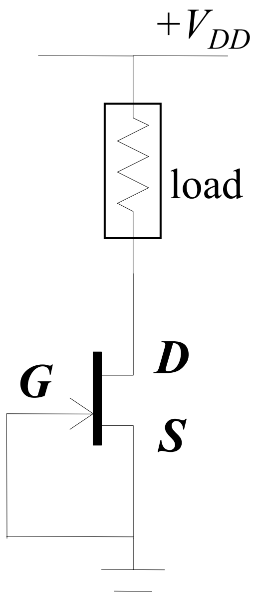
$$I_o = \frac{V_o}{R_i}$$ = "short circuit current" (load replaced by a short-circuit)

[V_o = open-circuit voltage]

since $$I = I_o - \frac{V}{R_i} = \frac{V_o}{R_i} - \frac{V}{R_i} \rightarrow V = V_o - R_i I$$

➨According to the value of Z_e/R_i ww have:
- -Voltage source ($Z_e >> R_i$)
- -Current source ($Z_e << R_i$)

FET-based current source



$$V_{GS} = 0 \quad \Rightarrow \quad I_D = I_{DSS}$$

Current corresponding to VGS=0

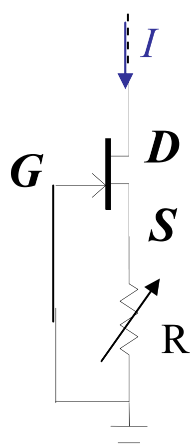
I_{DSS}= increases with V_{DS} ⇔ output resistance not infinite

Current can be tunable by addition of a variable resistor

$$\left.\begin{array}{l} I_D \cong I_{DSS}\left(1 - \dfrac{V_{GS}}{V_{GS_{off}}}\right)^2 \\ I_D = -\dfrac{V_{GS}}{R} \end{array}\right\} \rightarrow I_D$$

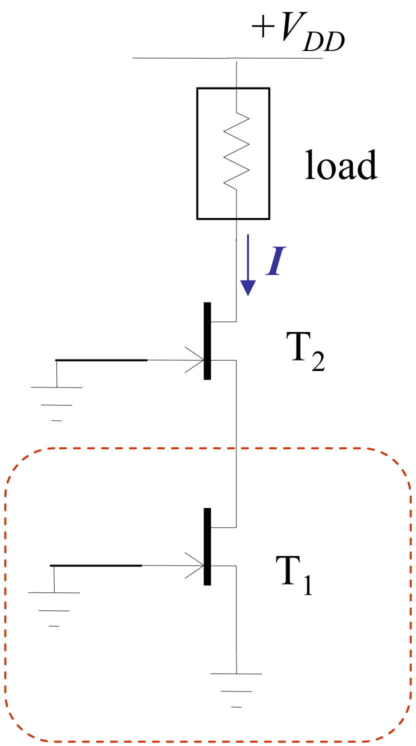
from transistor characteristics

I_{dds}: drain current with gate shorted to source



I_d and V_{GS} can be obtained by solving this system of equations

A better FET-based current source (greater output impedance)



Standard current source

T_2 and T_1 operate such that $I_{DSS}(T_2) > I_{DSS}(T_1)$

T_1 ➔ $I = I_{DSS}(T_1)$

➔ $V_{GS}(T_2)$ *is such that* $I_D(T_2) = I_{DSS}(T_1)$

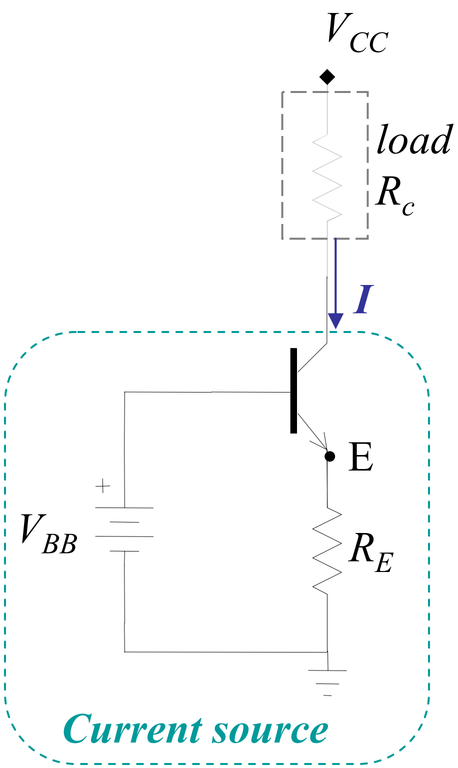
➔ $V_{DS}(T_1) = V_{GS}(T_2)$

➡ influence of load on $V_{DS}(T_1)$ is strongly reduced

➔ I vary less with respect to load variation

⇔ Ouput impedance is larger compare to the scheme presented in previous slide.

BJT as current sources



$$\rightarrow I \approx \frac{V_{BB} - 0.7V}{R_E}$$

V_{BE}~0.7 V implies active mode of operation So I_E=I_C

For any values of R_c …

as long as transistor operates in active mode

Operating domain : $(V_{BB} > 0.7V)$

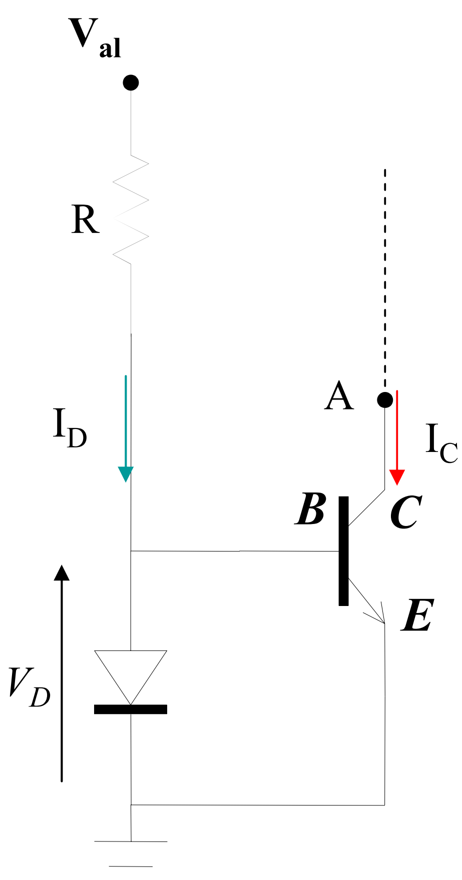
$$\approx 0 < V_{CE} = V_{CC} - (R_C + R_E)I_C < V_{CC}$$

- $$R_{c_{\max}} \cong \frac{V_{cc}}{I} - R_E$$

for $R_c > R_{cmax} \rightarrow$ *transistor in saturated regime*

BJT-based current source (current mirror)

Let's assume the characteristics *I(V)* of the diode is identical to the transistor BE junction



$$I_D \cong \frac{V_{al} - 0.7}{R}$$

V_{BE}~0.7 V implies active mode of operation So $I_E = I_C$

since $V_{BE} = V_D$

$\Rightarrow$ $I_C = I_D$

I_C is the « mirror image » of I_D…

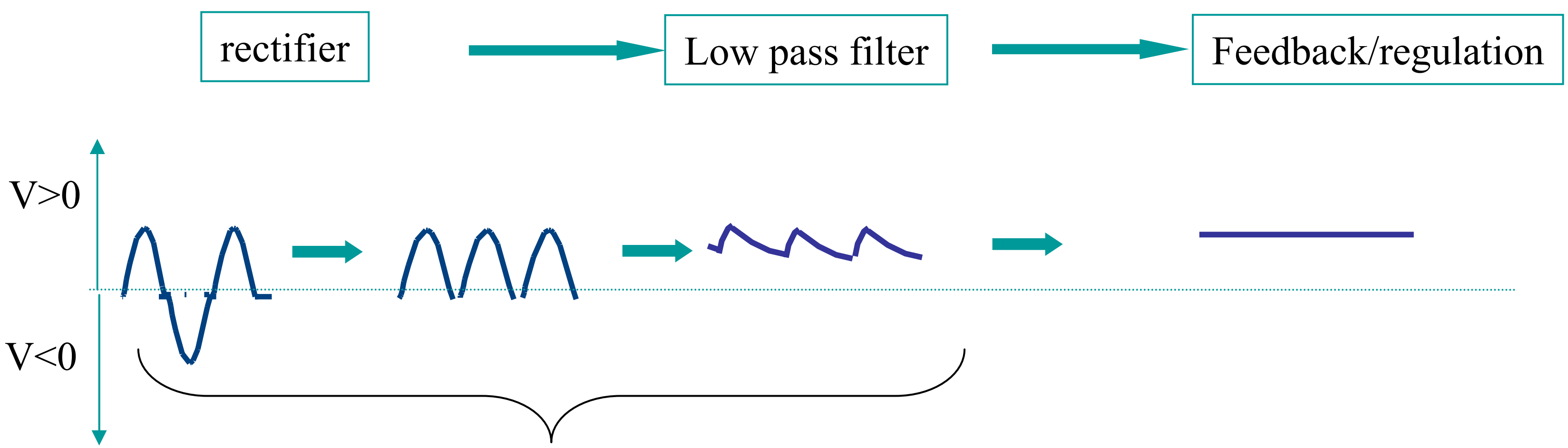
☒ *I* does not depend on the dashed circuit ⇔seen by A, the circuit behaves as a ideal current source (as long as the transistor operates in the active mode)

☒ In fact there is a small dependence of I_C upon V_{CE} ; this is refer to as Early effect (actually Early effect is the dependence of α_T on V_{CE}).

Diode and DC power supply

- **Aim:** Transform an AC signal in a DC signal.
  (e.g.: to supply DC voltage to an apparatus using the mains AC line)

The basis steps for an AC-to-DC converter are

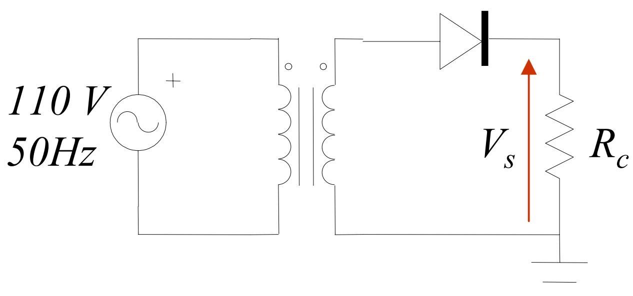


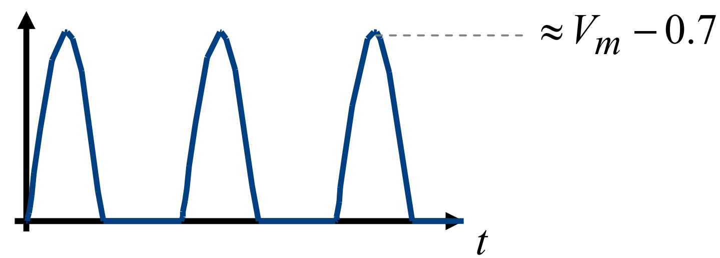
What you did in Lab #8

Rectification

V_s

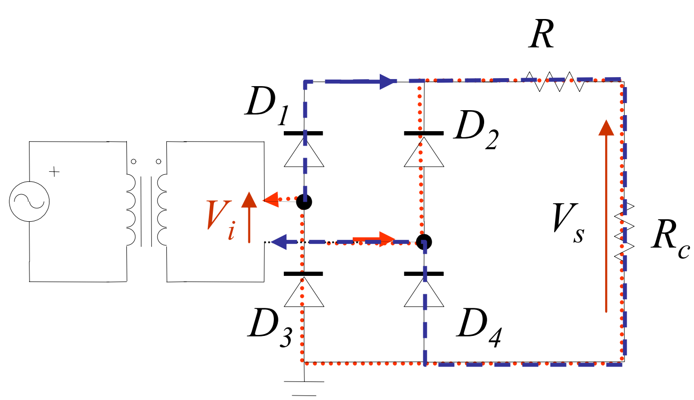
Single Rectification

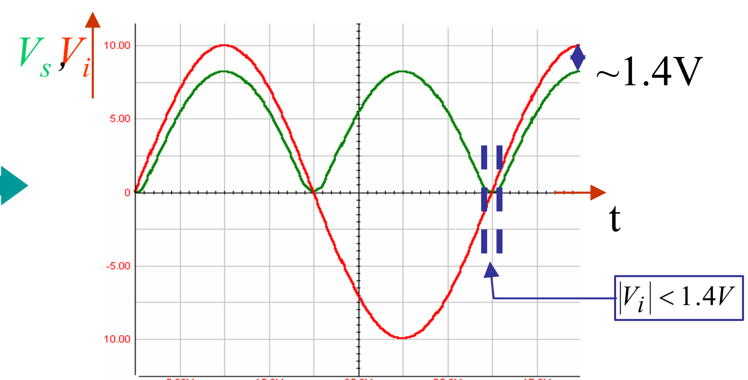




R_i =*output impedance of transformer*
V_m =*secondary circuit voltage*

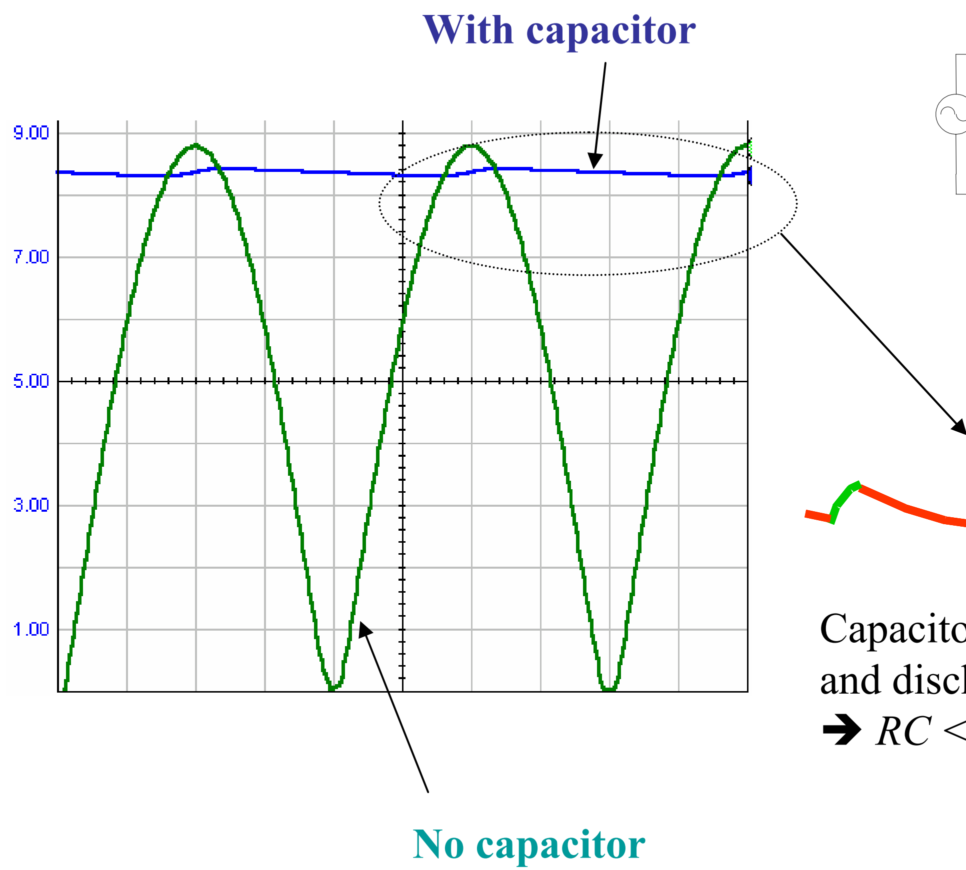
Double Rectification

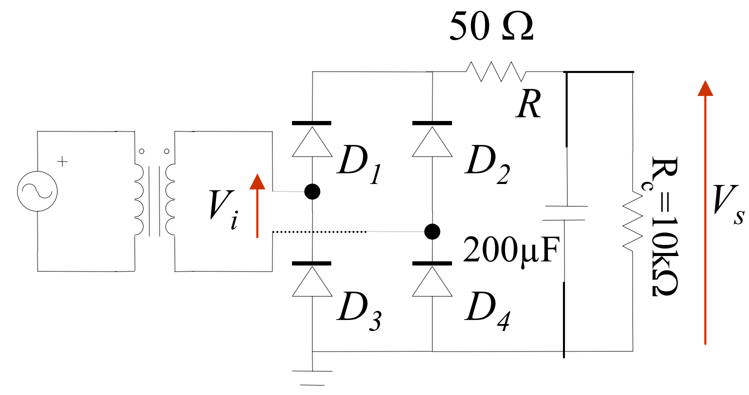




Rectification

With low frequency filtering



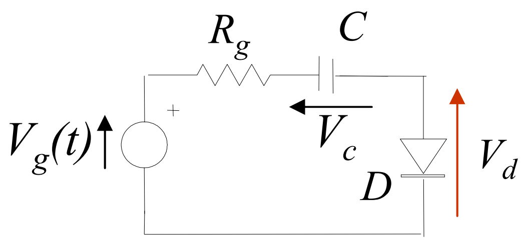


Capacitor charge through R
and discharge through R_c
➔ $RC << R_cC$

Clamping

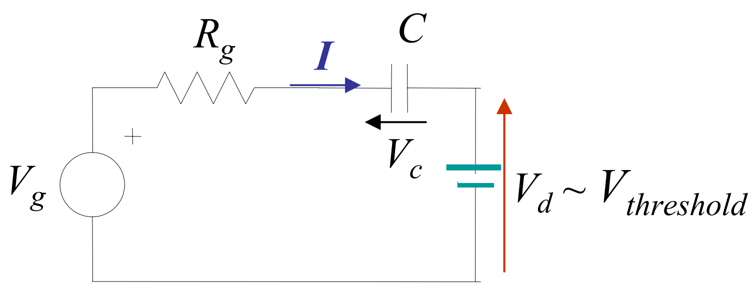
Fonction : Shift the signal toward positive (or negative) voltage
↔ Eventually get a DC signal with a non vanishing average value

Example :



Operation : *(assume a Si diode as we used in the Lab #8)*

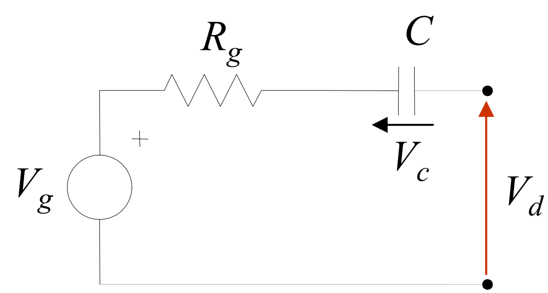
- When $V_g - V_c > V_{threshold}$, diode forward-biased



➔ C **charge** and V_c **goes toward** $V_g - V_{threshold}$

➔ $V_d \sim V_{threshold}$

- With $V_g - V_c < V_{threshold}$, diode reversed-biased



➔ V_c **= constant** (C cannot discharge!)

➔ $V_d = V_g - V_c$

~ DC component

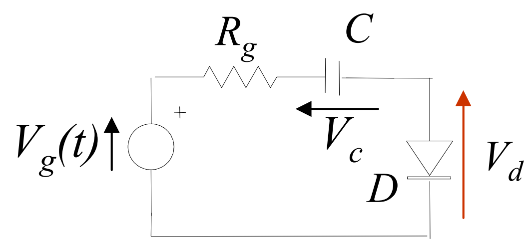
Clamping: example

- ***Example for a sinusoidal signal***

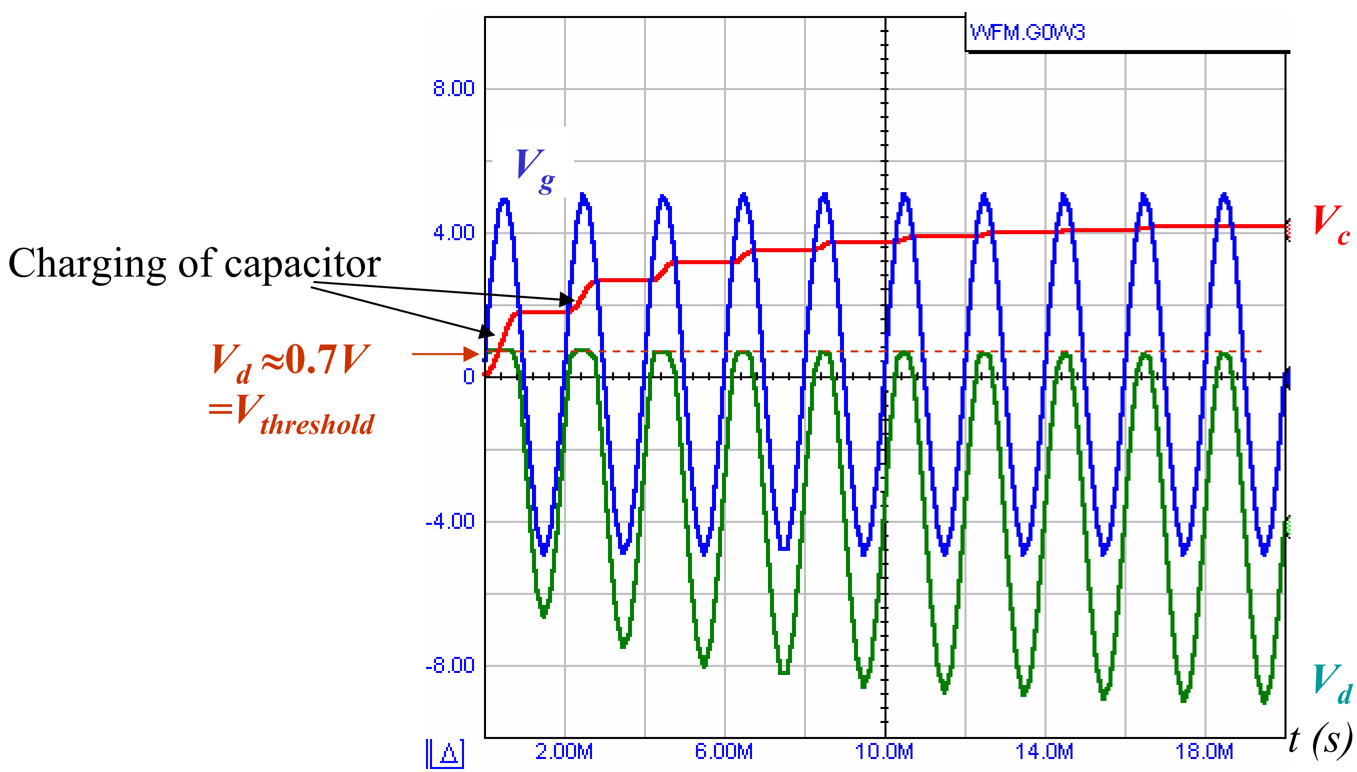
$$V_g = V_m \sin(\omega \cdot t) \quad \text{pour } t > 0$$

$$V_c = 0 \quad \text{pour } t < 0 \qquad \textit{(C discharged)}$$

➔ *Transient where capacitor is being charged*



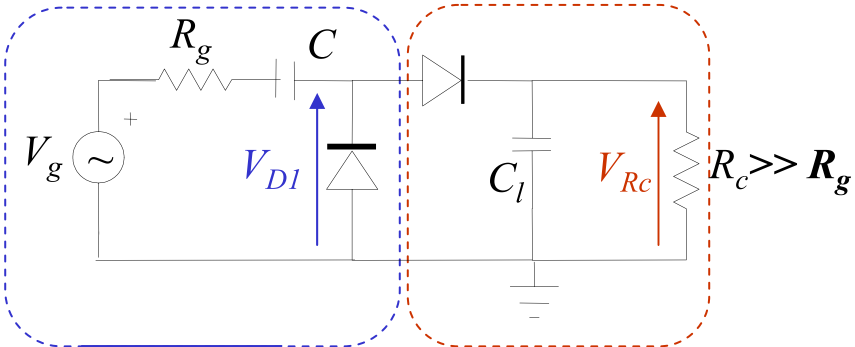
$C = 1\mu F$
$R_g = 1k\Omega$
$f = 100hz$
$V_m = 5V$



Voltage multiplier

Purpose : Produce a DC voltage from an AC input signal. The DC voltage is a multiple of input signal amplitude.

Example : Voltage Doubler



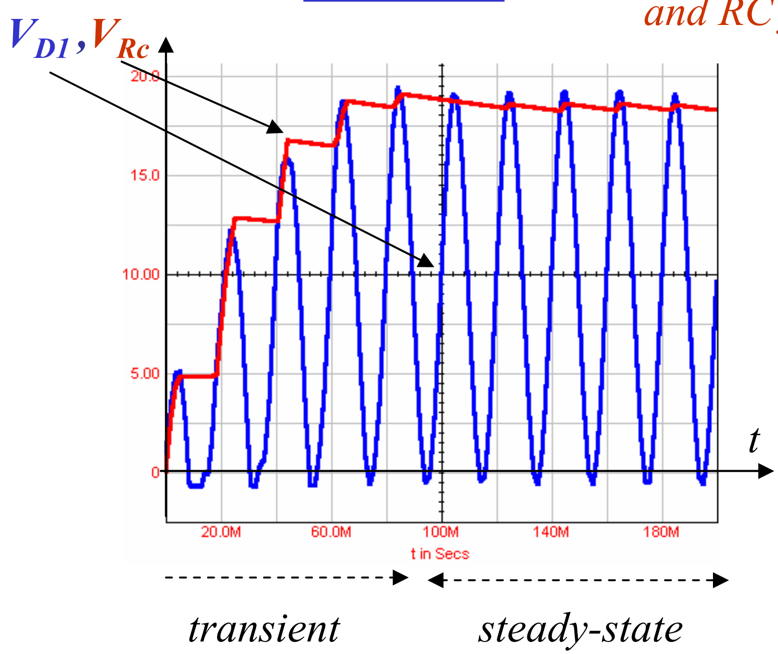
clamping

Single alternance rectifier and RC filter

$$V_g = V_m \sin(2\pi f \cdot t) \quad \text{for } t > 0$$

V_m=10V, f=50Hz, C=10μF

R_c=100kΩ.



* In steady state input current is small so high input impedance.

$$\rightarrow V_{R_c} \cong 2 \cdot V_m$$

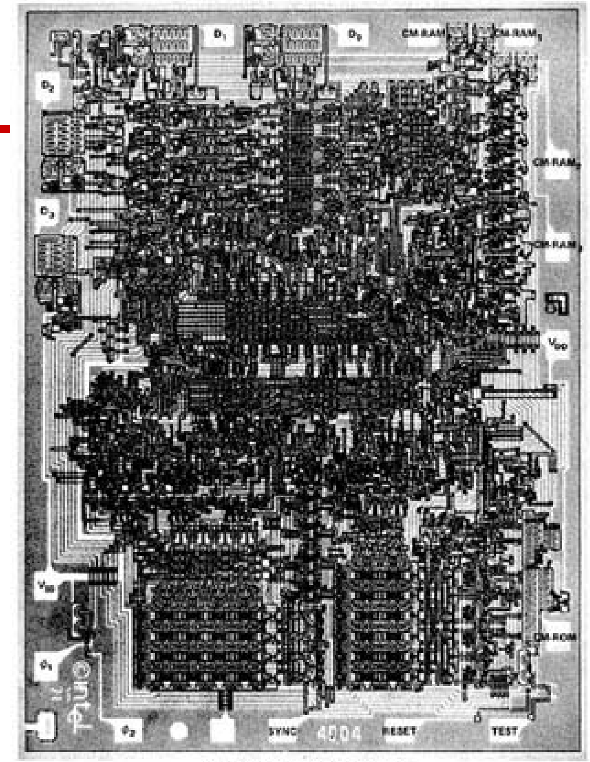
* This is not a good voltage source since output current (in R_c) must remain small (~ high internal impedance)

Summary

- Transistor and diode find many application in power supply (either as current of voltage source)

- Diode are used in scheme aimed at generating DC signal from an input AC signal

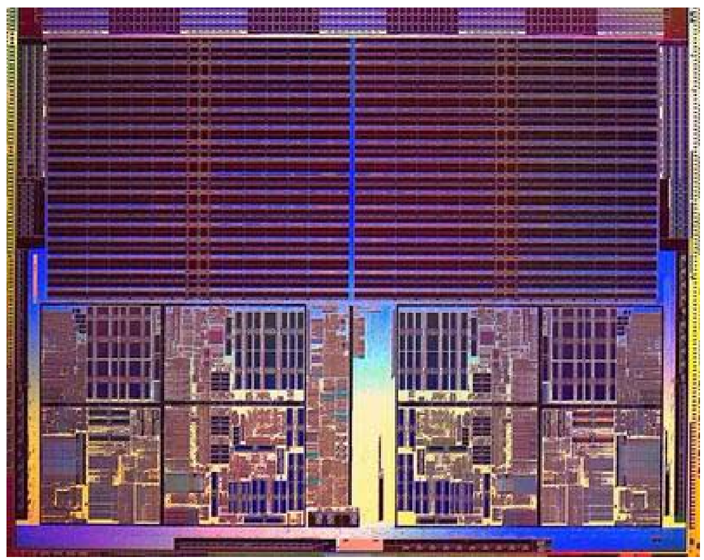
- There is another class of applications of transistor: amplifier



4004 Photomicrograph With Pin Designations

1971: intel processor 4004: 2250 transistors

1947: The 1st transistor



Today: ATHLON 64 dual core: 233000000 transistors